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<p>(54) Title: CONTACT LENSES AND METHODS OF MANUFACTURE</p> <div data-bbox="422 1113 1136 1680"> </div> <p>(57) Abstract</p> <p>The invention relates to a method of manufacturing a contact lens having an aspheric front surface computed by a method that allows total power control at each point of the lens by controlling power across the optic area of the lens, or each incremental part thereof. The lens can be monofocal, multifocal, toric, prismatic or a combination of these and be manufactured by any method such as lathe-cutting and cast-moulding. The lens can be manufactured to impart a chosen substantially uniform focal power over the optic area of the lens, or each incremental part thereof, either when in air or when part of the lens-eye system when in situ on the eye. The invention allows for the optimisation of the method of manufacturing the front surface of the lens, by fitting the most suitable mathematical equations dependent on the accuracy of the manufacturing equipment.</p>		

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**TITLE: CONTACT LENSES AND METHODS OF MANUFACTURE****Field of the Invention**

This invention relates to a contact lens and to a method of making a contact lens.

**Background to the Invention**

Contact lenses are generally designed to correct visual problems associated with focal power of the eye, and currently this is normally achieved by controlling the focal power of a contact lens using a selected combination of front and back surface curvatures, lens thickness and selection of lens material refractive index. In this way there is imparted to the contact lens a power appropriate to achieve some degree of correction for the optical defects of the eye of the wearer. Generally, however, the focal power cannot be fully controlled at all optical areas of the lens, resulting in the required focal power being only achieved at the central region of the useful optic area of the lens. One application of the present invention, is to control aberrations in the lens itself and of the lens eye system when the lens is in situ on the eye.

Other contact lenses, eg "aberration control" lenses, having a front aspheric surface curvature, are available eg from Lamda Polytech Limited and from Nissel Limited. However, these lenses are available only in very limited parameters (eg a soft lens of 38% Hema) and importantly are available only with a back surface curvature specified by the manufacturer.

Other inventions also describe methods of designing and manufacturing aberration control lenses. This includes "Aspherical lens, method of producing the lens and apparatus for producing the lens", publication number EP 0503111A1 by Kashiwagi, Toyohiko. However this and similar patents cover only the basic theory of aberration controlled lens design and manufacture but do not cover the application of these theories to material

behaviour during manufacture and the material behaviour on eye.

### **The Invention**

According to one aspect of the present invention, there is provided a method of making a contact lens, comprising the steps of: calculating the shape of an aspheric curve to be imparted to the front surface of the lens in order to provide a reduced differential in focal power over the optic region, or an incremental part thereof, of a monofocal or multifocal contact lens, by:-

- (a) estimating the required radius or profile of the front curvature of the lens or an incremental part thereof in order to achieve the correct prescribed focal power using standard or adapted thin lens formulae;
- (b) calculating the focal power of the lens by simulating the passage of parallel, or exceptionally non parallel, incident light rays through the lens at incremental distances in order to produce a power map of the lens detailing positions on the lens against the powers of the lens;
- (c) determining the profile of the power map for the lens or each incremental part thereof;
- (d) using an iterative process to estimate the necessary profile of each incremental part of the front surface and repeating steps (b) and (c) until the profile of the power map corresponds to a desired profile and accuracy.

Preferably, step (b) includes simulating the passage of light through the lens eye system, including the refractive surfaces within the lens eye system such as the tear layer, cornea, aqueous humour, crystalline lens and vitreous humour.

The refractive surfaces may include a change in the optical properties of the lens eye system by such as the inclusion of optical medical devices implanted into or onto the eye.

Step (c) may include representing the desired power map as a mathematical equation or series of equations. Conveniently, the mathematical equation or series of equations are a polynomial equation or series of polynomial equations.

Preferably, step (d) comprises:

- (e) defining an initial node position as a position on the front of the lens;
- (f) simulating the passage of parallel, or exceptionally non-parallel, incident light rays through the lens, taking into account the back surface geometry of the lens, at an incremented distance, adjusting the node position on the front surface of the lens, either closer or further away from the back surface of the lens, to a position which allows the refracted light rays to pass through the optical axis at the position indicated by the chosen defined power map;
- (g) defining a new node position on the front surface of the lens at a distance incremented from the previous node position;
- (h) repeating stages (f) and (g) until all selected nodal positions have been calculated to cover the desired area of the lens; and
- (i) using a mathematical fitting procedure, such as a polynomial curve fitting procedure, to fit a mathematical equation to the defined nodal positions.

The method may include defining the accuracy of the machining equipment and manufacturing process used to manufacture the lens and, at incremental values, relating the mathematical equation previously derived to the actual node position and investigating whether the node positions are within the previously defined accuracy of the machining equipment and manufacturing process. The method may use a mathematical equation such as a polynomial curve of sufficient order or higher, until the profile or all of the node positions are defined to the required accuracy.

Where the contact lens is considered flexible, such as a soft hydrogel or silicon lens, the method includes calculating a shape change function from the difference between the back surface shape of the lens and the resultant shape of the back surface of the lens once in situ on the eye, and incorporating the change in conic eccentricity of the back surface of the contact lens where applicable, and applying the shape change function to the derived mathematical equation defining the front geometry of the lens.

Where the contact lens is manufactured from a material which exhibits shape changing properties such as expansion or shrinkage, the method may include calculating the necessary shape change function from the material properties of the lens which may or may not be isotropic, and incorporating the change in conic eccentricity of the lens surfaces where applicable, and applying the shape change function to the defined parameters of the lens.

The present invention, in its preferred form, is a great improvement as it provides a method of manufacturing a contact lens which has fully controlled power distribution at all optical parts of the lens, both in air and as part of the lens eye system when in situ on eye, and definable with any lens material and specification including any desired back surface curvature (eg spherical, aspherical or polynomial) as specified by the manufacturer or by a practitioner fitting the lens. Additionally the present invention enables the optimisation of the lens manufacturing process for producing the appropriate front surface of the lens by accounting for the accuracy of the manufacturing process and equipment. The present invention is applicable to all lens types including monofocal, multifocal, prismatic, toric lenses and combinations thereof.

Furthermore, the present invention, in its preferred form, takes into consideration the effect of shape changes in the lens due to the draping of the lens when in situ on the eye and shape changes to the lens material during manufacture.

If the contact lens contains a toric portion, whether on the back, front or both surfaces, the above process is repeated across each axis of the toric portion.

If the contact lens contains a prismatic portion or portions, step (b) is accommodated to include the offset surfaces.

Using the above-stated method, the profile of the front surface curvature for the contact lens can be determined. The lens can then be manufactured using conventional modern contact lens manufacturing techniques such as computer numerical control (CNC) lathe cutting and cast moulding.

The invention also relates to a contact lens having an aspheric front surface the shape of which is computed by the inventive method.

Preferably, the contact lens according to the invention has a single, substantially uniform focal power across substantially the entire optic area of the lens, or each incremental part thereof.

For the purposes of the present specification, a lens may be considered to have a "substantially uniform" focal power across its optic area, or each incremental part thereof, if, for a typical lens, the focal power deviates by less than 1 dioptre, preferably less than 0.5 dioptries, and more preferably by less than 0.25 dioptries.

For present purposes, the optic area of the lens may be defined as that part of the surface of the lens falling within a circle, which circle is centred on the centre of the lens and which has a diameter equal to the front optic zone diameter (FOZD) of the lens. The FOZD of a lens is defined in ISO 8320-1986. In general, the FOZD is the diameter of that portion of the front surface of the lens which is intended to provide the desired optical correction to the wearer of the lens. A contact lens may be made so as to have a FOZD of any desired size. The FOZD will normally be determined primarily by the total diameter of the lens. For example, a typical rigid gas permeable (RGP) lens of single power may have a total diameter of 9.5mm, and the FOZD of such a lens will typically be in the range 6-8.5mm. An average soft lens, with a total diameter of 14mm, might typically have an FOZD in the range 8-11mm.

It will be apparent to those skilled in the art that, for lenses with a particularly large FOZD, it may not be necessary for the entire optic area to be designed so as to be aspheric, as light passing through the periphery of such a lens with a large FOZD (and hence a large optic area) may not enter the pupil of the wearer or is unlikely to be incident upon the retina near the fovea.

Accordingly, "substantially the entire optic area" of the lens in accordance with the invention may be around 65% of the optic area for a lens with a large FOZD, but will preferably be at least 75%, more preferably at least 80% and most preferably at least 90% of the optic area for more normal lenses in accordance with the invention.

As asphericity is imparted only to the front surface (ie that surface of the contact lens further from the cornea of the wearer) for controlling focal power, the curvature of the back surface remains determinable by the manufacturer or the optician fitting the lens. In this connection, the back surface may be selected to be either spherical or aspheric for the purpose of aiding fitting to the eye.

The invention is applicable to all types of contact lens (rigid or soft), regardless of material or replacement frequencies, such as

- a) soft disposable spherical lenses
- b) soft disposable toric lenses
- c) soft disposable multifocal lenses
- d) soft spherical lenses
- e) soft toric lenses
- f) soft multifocal lenses
- g) rigid gas permeable (RGP) spherical and back aspheric and polynomial lenses
- h) RGP toric lenses
- i) RGP bifocal lenses

When applying this invention for reducing spherical aberration in either the lens or the lens-eye system, the invention may offer the following benefits to the wearer of contact



lenses:

a) Increased all-round acuity

The wearer will be attaining the prescribed power correction; generally, contact lenses give an average power correction which is dependent on the prescribed power and lens-induced spherical aberration effects.

b) Increased visual acuity in low light conditions

In low light conditions, the pupil of the wearer expands. This allows more light through peripheral areas of the contact lens where, in conventional contact lenses, the focal power deviates from the prescribed power. This may also cause halo/flare effects. This effect is significantly reduced when the prescribed power is constant over substantially the complete optic area, as in lenses in accordance with the present invention.

c) Increased lens movement

Lens movement helps induce tear flow underneath the contact lens which leads to healthier conditions, by increasing oxygen availability for the eye. Currently, lens movement (especially lens movement caused by blinking) means that the wearer momentarily looks through areas other than the centre and therefore through incorrect power regions. Increased lens movement is permissible for lenses that have the prescribed power across the complete optic area, as the wearer will not perceive any loss of visual acuity.

d) Easier fitting for practitioners

The need to ensure absolute centring of the lens is not required as the wearer may still obtain the best visual acuity without looking directly through the exact lens centre. This will increase first time fit success, which offers a considerable commercial advantage.

### **Description of Drawings**

The invention is further described with reference to the accompanying drawings, in

which:-

Figures 1 to 6 are explanatory diagrams to aid understanding the method of calculating the shape of the front surface of a contact lens in order to produce substantially uniform focal power across the useful optic area or incremental parts thereof;

Figure 7 comprises graphs showing the theoretical focal powers of lenses 1 and 2 of two pairs of lenses A and B, in each case lens 1 having an aspheric front surface modification by means of the present invention and lens 2 having a spherical front surface; and

Figures 8A to 8D are representations of focal power maps relating to the lens pairs A and B.

### **Description of Examples**

There will now be described, by way of example, a method in accordance with the invention for calculating the asphericity of the front surface of a contact lens.

#### **Example 1**

Figure 1 shows the relevant terms and definitions:-

#### **Focal Power Definitions**

BVP	Back vertex power
L	Focal length
Y	Distance from centre of lens

#### **Back Surface Definitions**

TD	Total diameter of the lens
BOZD	Back optic zone diameter

BOZR	Back optic zone radius
Be	Back optic zone eccentricity

#### Front Surface Definitions

FOZD	Front optic zone diameter
FOZR	Front optic zone radius
Fe	Front optic zone eccentricity

#### Thicknesses

Tc	Centre thickness
Tj	Junction thickness
Te	Edge thickness

Making reference to Figure 2, the first step of the method comprises;

- (a) estimating the required radius or profile of the front curvature of the lens or an incremental part thereof in order to achieve the correct prescribed focal power using standard or adapted thin lens formulae;

```
Function FOZR(BOZR,Tc,Ri,BVP);
var focia,focib;real;
begin

focia:=(1-Ri)*1000/BOZR;
focib:=1000/((1000/(BVP-focia))+(Tc/Ri);
FOZR:=(Ri-1)*1000/focib;
end;
```

- (b) calculating the focal power of the lens by simulating the passage of parallel, or exceptionally non parallel, incident light rays through the lens at incremental distances in order to produce a power map of the lens detailing

positions on the lens against the powers of the lens;

The second step of the method comprises incrementing Y from 0.00 to FOZD/2 in incremental steps.

In order to calculate passage of initial parallel light ray, the angles at which the light ray refracts from each external and internal surface are required. These angles relate to the angle between the incident light ray and the perpendicular of the surface at that point.

Making reference to Figure 3, the calculation of the perpendicular at the point of contact comprises:-

Equation for aspheric curve:

$$x = \text{sqr}(y) / (r + \text{sqr}(\text{sqr}(r) + (a * \text{sqr}(y))));$$

where  $a = -(1 + \text{sqr}(e))$  (for calculating the back surface curve,  $e = Be$  and  $r = BOZR$ ; for calculating the front surface,  $e = Fe$  and  $r = FOZR$ ).

To find the tangent of this curve, the above equation is differentiated with respect to y.

$$dx/dy = y * (2 * z * (r + z) - (a * \text{sqr}(y))) / z * \text{sqr}(r + z)$$

$$\text{where } z = \text{sqr}(\text{sqr}(r) + (a * \text{sqr}(y)))$$

$$\text{and } a = -1(+\text{sqr}(e))$$

To find the perpendicular of this curve:

$$-dy/dx = -z * \text{sqr}(r + z) / y * (2 * z * (r + z) - (a * \text{sqr}(y)))$$

This allows calculation of angles A and B:

$$A = \tan^{-1}(-dy/dx)$$

$$B = \sin^{-1}(\sin(A)/Ri)$$

where  $x$  = sagittal depth of front curve at position  $Y$

$y$  = position  $Y$

$R_i$  = refractive index of the contact lens material; and

the calculation of angles  $C$  and  $D$ :

$$C = \tan^{-1}(-dy_1/dx_1) - (\tan^{-1}(-dy/dx) - B);$$

$$D = \sin^{-1}(R_i \sin(C))$$

where  $x_1$  = sagittal depth of back curve at position  $Y$

$y_1$  = position  $Y$  (note that the position  $Y$  on the back surface is calculated from the angle  $B$  and the thickness of the lens using an iterative method).

The calculation of angle  $E$  and focal length ( $L$ ) comprises:

$$E = \tan^{-1}(-dy_1/dx_1) - D$$

$$L = y / \tan(E)$$

where  $x_1$  = sagittal depth of back curve at position  $Y$

$y_1$  = position  $Y$

The calculation of back vertex power (BVP) comprises:-

$$BVP = 1000/L$$

The calculation is repeated for all values of  $Y$  up to  $FOZD/2$

Step (c) of the method follows and entails:-

- (c) determining the profile of the power map for the lens or each incremental part thereof;

Using a memory device, store all values of BVP at incremental distances within the lens optical area or incremental section thereof;

Step (d) comprises:

- (d) using an iterative process to estimate the necessary profile of each incremental part of the front surface and repeating steps (b) and (c) until the profile of the power map corresponds to a desired profile and accuracy.

The front eccentricity value and front radius of the lens or each incremental part is adapted in an iterative process, then the process is repeated until the profile of the power map corresponds to the desired profile.

The previous equations may be extended to incorporate the additional refracting surfaces of the eye, which include the tear lens, cornea, aqueous humour, crystalline lens and vitreous humour. This will allow for the control of power at each part of the contact lens in the complete lens eye system. The shape of the tear lens is determined by the back surface of the contact lens and the front of the cornea (which is typically measured by the practitioner, using keratometry). For a flexible lens, any drape of the lens is taken into account. The thickness of the tear layer is estimated from the geometrical point of contact between the lens and the cornea (typically in the range 5-10 $\mu$ m). For the purposes of the determining the geometry of the other refractive surfaces within the eye, a modified schematic of the Gullstrand number 1/2 model or the Le Grand model may be used.

With reference to Figure 5, and to the preceding calculations, the calculation of angle D is modified such that:

$$D = \sin^{-1}(R_{i_c} \sin(C)/R_{i_1})$$

With reference to Figure 5, the incident and refractive angles of the light ray at the refractive surfaces in the eye are as follows:

$$F = \tan^{-1}(-dy_n/dx_n) - (\tan^{-1}(-dy_{n-1}/dx_{n-1}) - D)$$

$$G = \sin^{-1}(R_{i_n} \sin(F)/R_{i_{n+1}})$$

Where  $D$  = previous angle of refraction

$F$  = angle of incidence

$G$  = new angle of refraction

$x_{n-1}$  = sagittal depth of previous refracting surface at position  $Y$

$y_{n-1}$  = previous position  $Y$  having been adjusted in relation to the angle of the incident ray.

$x_n$  = sagittal depth of refracting surface at position  $Y$

$y_n$  = position  $Y$  having been adjusted in relation to the angle of the incident ray and the distance the ray has travelled.

$Ri_n$  = refractive index of the incident medium

$Ri_{n+1}$  = refractive index of the refracting medium

This is repeated through all refracting surfaces of the eye indicated on Figure 5.

The calculation of angle  $E$  and focal length ( $L$ ) is as follows:

$$E = G - \tan^{-1}(-dy_s/dx_s)$$

$$L = y/\tan(E) + \text{distance from the cornea to the final refracting surface}$$

Where  $x$  = sagittal depth of the final refracting surface

$y$  = position  $Y$  having been adjusted in relation to the angle of the incident ray

The calculation of back vertex power (BVP) is then consistent with the equations detailed previously.

According to a preferred feature of the invention, the iterative process to calculate the shape of the front curve imparted to the front surface contact lens may or may not be limited to either one or a series of aspheric curves described using the equation:

$$x = \text{sqr}(y)/(r + \text{sqr}(\text{sqr}(r) + (a * \text{sqr}(y))))$$

but impart either one or a series of polynomial equations as follows:

- (e) defining an initial node position as a position on the front of the lens;

With reference to Figure 6, at an incremental distance from the central axis through the contact lens, define nodes  $x_0, y_0, x_1, y_1$ ,

Where  $x_0 = -Tc$   
 $y_0 = 0$   
 $x_1 = -Tc$   
 $y_1 = \text{incremental distance from the central axis}$   
 $Tc = \text{Centre thickness of the lens}$

- (f) simulating the passage of parallel, or exceptionally non parallel, incident light rays through the lens, taking into account the back surface geometry of the lens, at an incremented distance, adjusting the node position on the front surface of the lens, either closer or further away from the back surface of the lens, to a position which allows the refracted light rays to pass through the optical axis at the position indicated by the chosen defined power map;

In reference to Figure 6, the path of the parallel incident light ray is calculated using the previous equations for determining the angle of incidence and refraction where:

for example  $dy/dx = (y_n/y_{n-1})/(x_n/x_{n-1})$

An iterative process is used to adjust the position of  $x_n$  until the resulting value for BVP is equal to the desired power profile at incremental distance  $y$  from the central optical axis of the contact lens. The value for  $x_n$  is stored against value  $y_n$  in a memory device.

- (g) defining a new node position on the front surface of the lens at a distance incremented from the previous node position;

Where  $x_n = x_{n-1}$   
 $y_n$  is incremented



- (h) repeating stages (f) and (g) until all selected nodal positions have been calculated to cover the desired area of the lens; and

Where  $y_n = FOZD/2$

- (i) using a mathematical fitting procedure, such as a polynomial curve fitting procedure, to fit a mathematical equation to the defined nodal positions.

Define a polynomial equation to the stored values of  $x_0$  to  $x_n$  against the incremented values of  $y_0$  to  $y_n$  using standard best fit criteria.

An iterative process is used to determine the order of the polynomial equation necessary to describe the nodal points  $x_0$  to  $x_n$  against the incremented values of  $y_0$  to  $y_n$  to the accuracy required by the manufacturing process. Preferably, the polynomial equation must describe the position of the nodal points to an accuracy of  $\pm 2\mu\text{m}$ , more preferably to an accuracy of  $\pm 1\mu\text{m}$  and most preferably to an accuracy of  $\pm 0.5\mu\text{m}$ .

According to yet another preferred feature of the invention, the shape imparted to the front surface of a flexible lens is compensated for the action of the contact lens draping on the surface of the eye.

Using the standard equation of a curve with asphericity, the back surface of the contact lens is described:-

$$y = x^2/r - \sqrt{r^2 - ax^2}$$

where  $a$  = measure of asphericity of the curve.

By using shape change factors  $t_y$  and  $t_x$ , the above equation is adapted such:

$$y'/t_y = x'^2/t_x^2/r - \sqrt{r^2 - ax'^2/t_x^2}$$

therefore

$$y' = x'^2/r' - \sqrt{r'^2 - a'x'^2}$$

where  $r' = rt_x^2/t_y$   
 $a' = at_x^2/t_y^2$

The shape change factors  $t_y$  and  $t_x$  are determined for a flexible lens where:

- $r$  = radius of the standard cornea
- $a$  = asphericity of the standard cornea
- $r'$  = radius of the back surface of the flexible contact lens
- $a'$  = asphericity of the back surface of the flexible contact lens

The shape change factors  $t_y$  and  $t_x$  are applied directly to the polynomial equation describing the front surface of the flexible contact lens.

When determining the front and back curve radii and asphericity of the contact lens when the material that the contact lens is manufactured from is in a state of pre-hydration, the determination of the shape change factors  $t_x$  and  $t_y$  in this instance correspond respectively to the axial and the radial expansion factors of the material.

### Example 2

Again making reference to Figure 1, examples of contact lenses having aspheric front surfaces in accordance with the invention are given below. The contact lenses manufactured in accordance with the invention, having substantially uniform focal power across substantially the entire optic area, are aplanatic lenses corrected for induced spherical aberration, and are now referred to as such. These aplanatic lenses are compared with non-aplanatic contact lenses computed conventionally and having spherical front surfaces.

Thus, two lens pairs A and B each having aplanatic lens 1 and non-aplanatic, standard lens 2 are compared:-

	Lens Pair A		Lens Pair B	
	Lens 1	Lens 2	Lens 1	Lens 2
BOZR	8.00	8.00	8.00	8.00
TD	9.50	9.50	9.50	9.50
FOZD	8.00	8.00	8.00	8.00
FOZR	7.21	7.21	9.21	9.21
BVP	+ 8.00	+ 8.00	- 8.00	- 8.00
Tc	0.35	0.32	0.14	0.14
Fel	0.471	0.00	- 0.627	0.00
Aplanatic	Yes	No	Yes	No

The lenses were manufactured using standard materials (PMMA - polymethyl methacrylate) and standard contact lens lathe cutting equipment and measured using a Visionix VC2001 lens mapping system,

Figure 7 shows the theoretical or predicted power distributions over the useful, optic areas of the lenses of pair A (at the top) and pair B (below). The graphs plot focal power (DS) against distance from the lens centre in mm and it can readily be seen that, for each pair, lens 1, the aplanatic lens, theoretically has a uniform power distribution over the useful optic area, whilst in each case lens 2, the non-aplanatic lens, shows a focal power increasing or decreasing from the power at the centre of the lens.

Figures 8A to 8D are power distribution maps for contact lenses 1 and 2 of pairs A and B, obtained subsequent to manufacture. Each map is associated with a key in the form of focal power scale.

The inner circle in each map defines the useful, optic area of the lens, and it can readily

be seen that, for each pair, within these areas, lens 1 of the pair has substantially uniform focal power relative to lens 2.

In conclusion, the invention as described enables contact lenses to be manufactured with substantially constant focal power across a desired diameter; applies to all designs of contact lenses, whichever manufacturing process is used, without altering the fitting characteristics of the lens; offers significant clinical and commercial advantages; and enables contact lenses to be manufactured using standard equipment, of all modalities and techniques, and therefore does not increase running costs of manufacture.

### Claims

1. A method of making a contact lens, comprising the steps of: calculating the shape of an aspheric curve to be imparted to the front surface of the lens in order to provide a reduced differential in focal power over the optic region, or an incremental part thereof, of a monofocal or multifocal contact lens, by:-

- (a) estimating the required radius or profile of the front curvature of the lens or an incremental part thereof in order to achieve the correct prescribed focal power using standard or adapted thin lens formulae;
- (b) calculating the focal power of the lens by simulating the passage of parallel, or exceptionally non parallel, incident light rays through the lens at incremental distances in order to produce a power map of the lens detailing positions on the lens against the power of the lens;
- (c) determining the profile of the power map for the lens or each incremental part thereof;
- (d) using an iterative process to estimate the necessary profile of each incremental part of the front surface and repeating steps (b) and (c) until the profile of the power map corresponds to a desired profile and accuracy.

2. A method according to claim 1, wherein step (b) includes simulating the passage of light through the lens eye system, including the refractive surfaces within the lens eye system such as the tear layer, cornea, aqueous humour, crystalline lens and vitreous humour.

3. A method according to claim 2, wherein the refractive surfaces include a change in the optical properties of the lens eye system by such as the inclusion of optical medical devices implanted into or onto the eye.

4. A method according to claim 1, wherein step (c) includes representing the desired power map as a mathematical equation or series of equations.
5. A method according to claim 4, wherein the mathematical equation or series of equations are a polynomial equation or series of polynomial equations.
6. A method according to any of the preceding claims, wherein step 1(d) comprises:
  - (e) defining an initial node position as a position on the front of the lens;
  - (f) simulating the passage of parallel, or exceptionally non-parallel, incident light rays through the lens, taking into account the back surface geometry of the lens, at an incremented distance, adjusting the node position on the front surface of the lens, either closer or further away from the back surface of the lens, to a position which allows the refracted light rays to pass through the optical axis at the position indicated by the chosen defined power map;
  - (g) defining a new node position on the front surface of the lens at a distance incremented from the previous node position;
  - (h) repeating stages (f) and (g) until all selected nodal positions have been calculated to cover the desired area of the lens; and
  - (i) using a mathematical fitting procedure, such as a polynomial curve fitting procedure, to fit a mathematical equation to the defined nodal positions.
7. A method according to claims 5 and 6, and including defining the accuracy of the machining equipment and manufacturing process used to manufacture the lens and, at incremental values, relating the mathematical equation derived at claim 5 or 6(i) to the actual node position and investigating whether the node positions are within the previously defined accuracy of the machining equipment and manufacturing process.

8. A method according to claim 7, but using a mathematical equation such as polynomial curve of sufficient order or higher, until the profile or all of the node positions are defined to the required accuracy.
9. A method according to any of the preceding claims, where the contact lens is considered flexible, such as a soft hydrogel or silicon lens, and calculating a shape change function from the difference between the back surface shape of the lens and the resultant shape of the back surface of the lens once in situ on the eye, and incorporating the change in conic eccentricity of the back surface of the contact lens where applicable, and applying the shape change function to the derived mathematical equation defining the front geometry of the lens.
10. A method according to any of the preceding claims, where the contact lens is manufactured from a material which exhibits shape changing properties such as expansion or shrinkage, and calculating the necessary shape change function from the material properties of the lens which may or may not be isotropic, and incorporating the change in conic eccentricity of the lens surfaces where applicable, and applying the shape change function to the defined parameters of the lens.
11. A contact lens manufactured by a method according to any of the preceding claims.

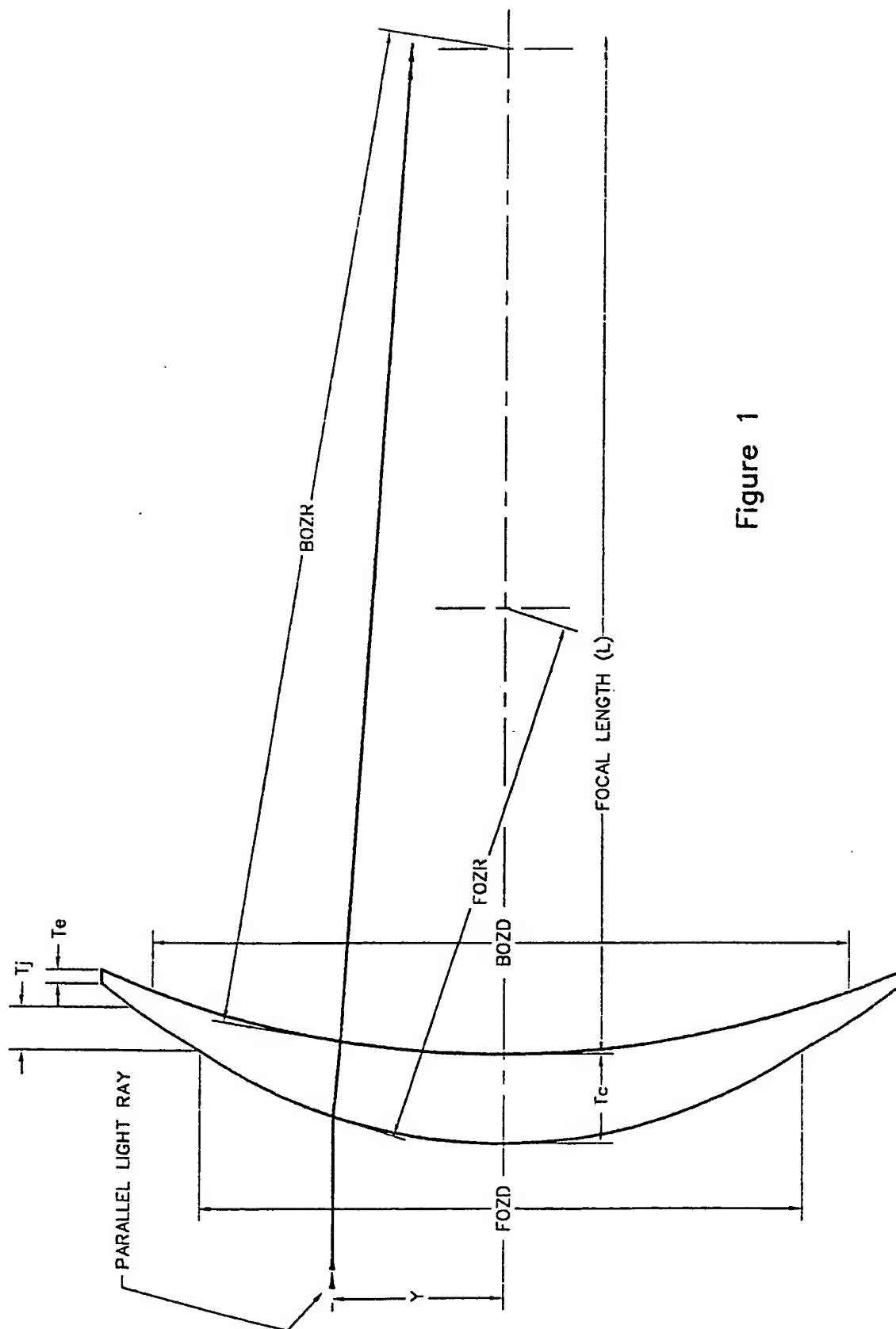
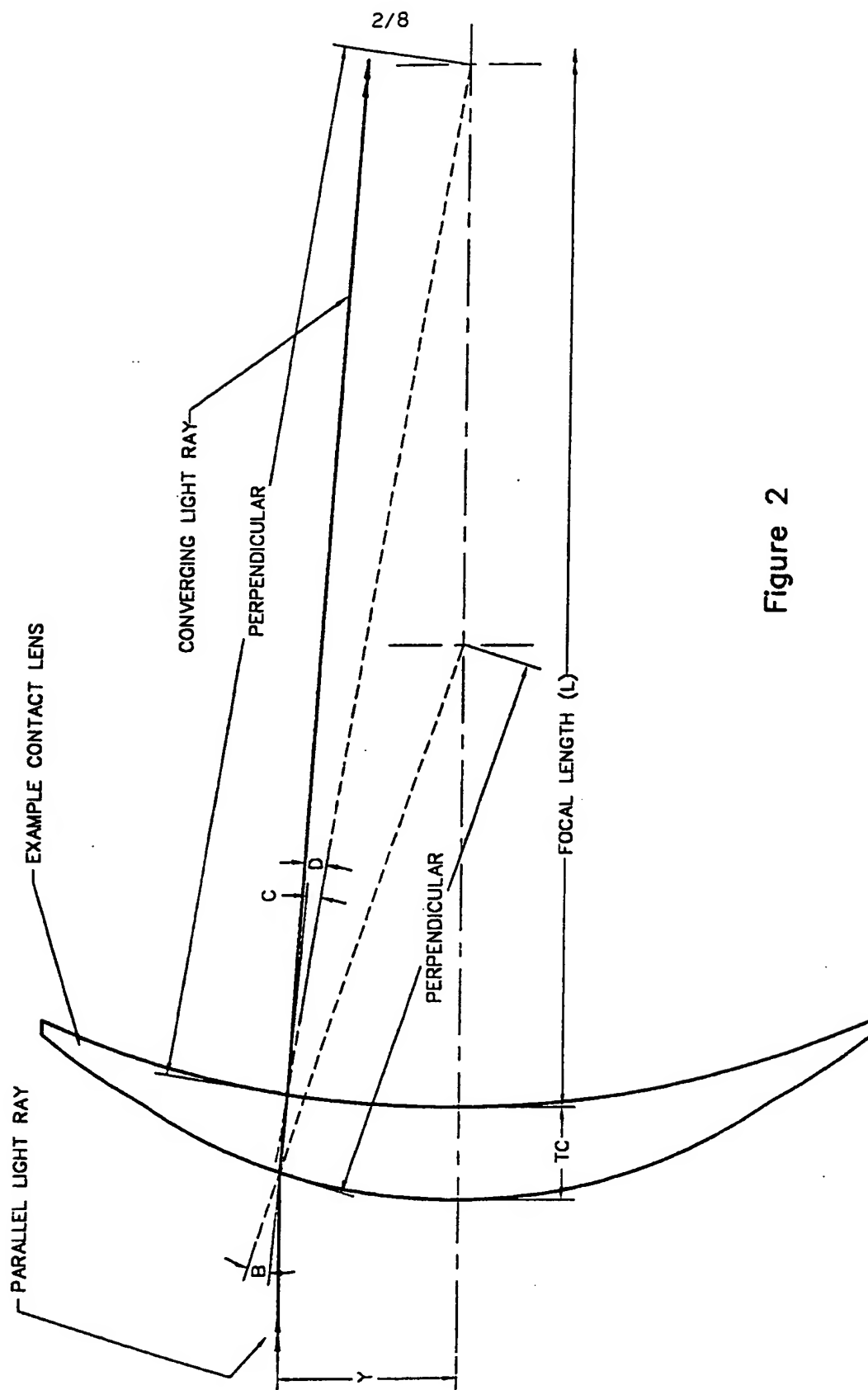


Figure 1





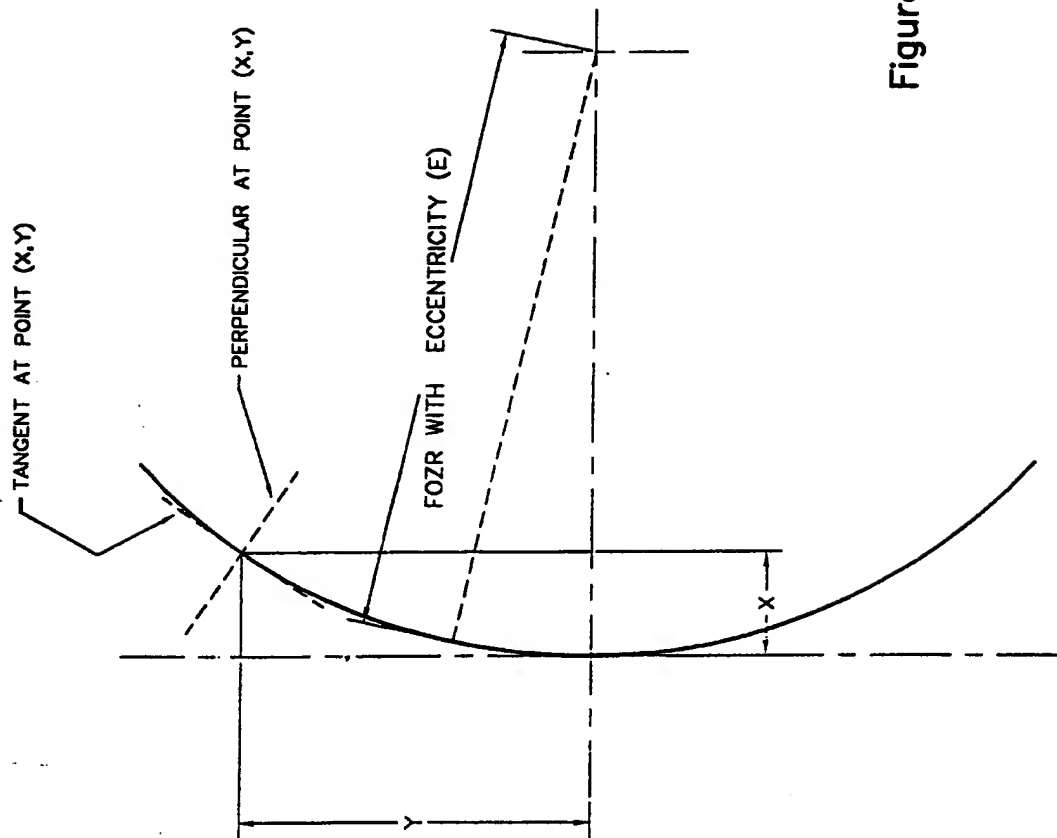


Figure 3

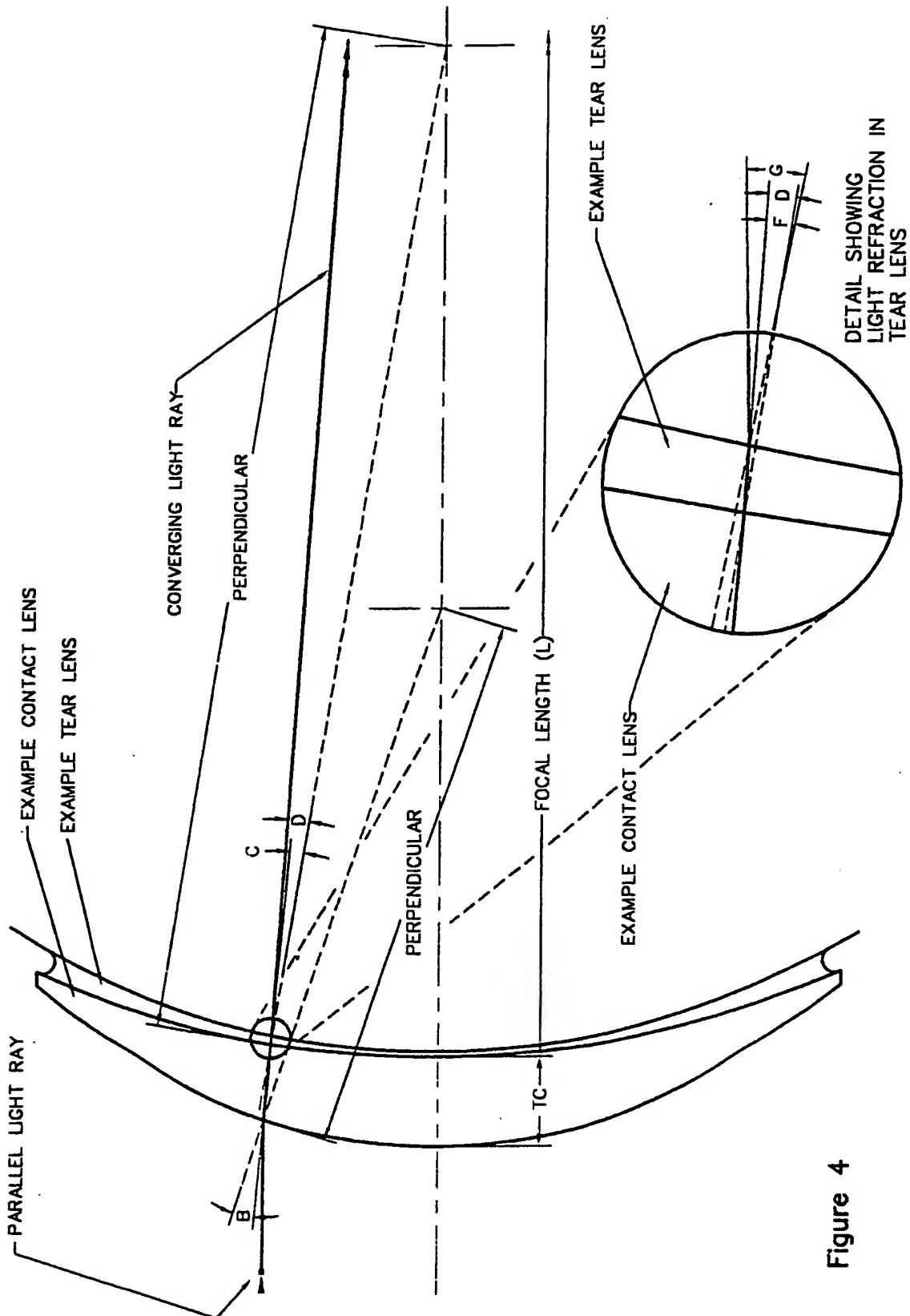


Figure 4

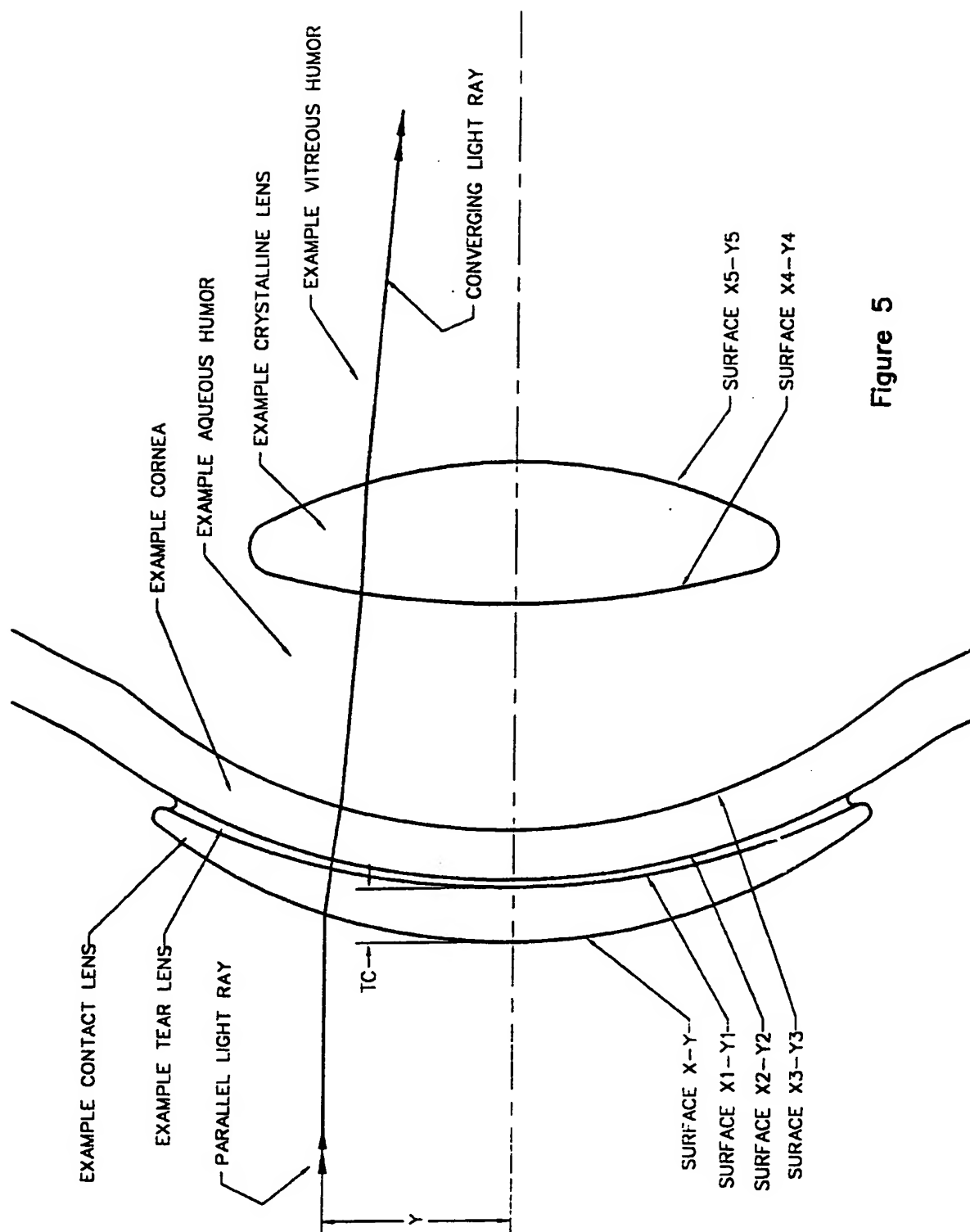


Figure 5

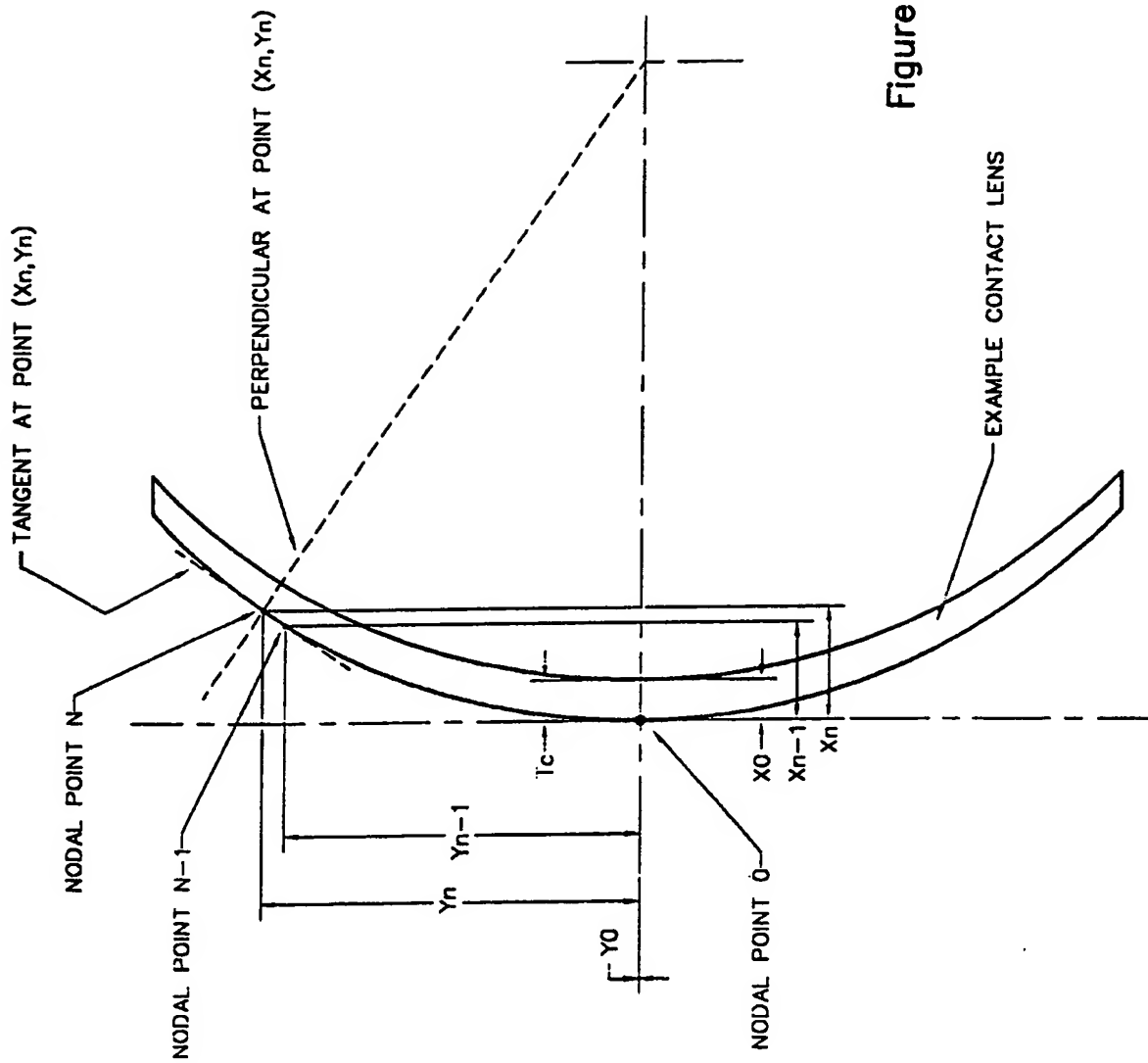
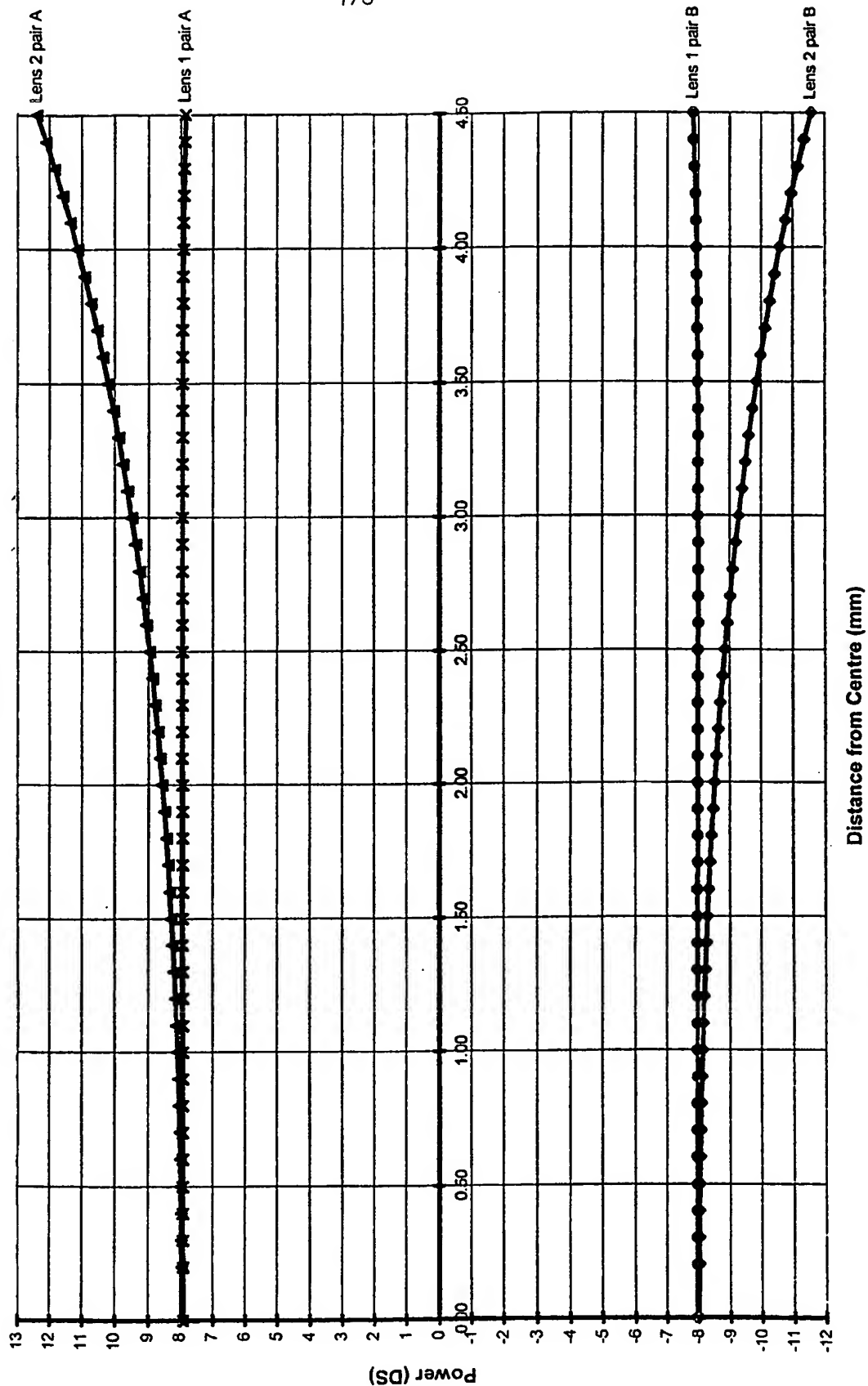
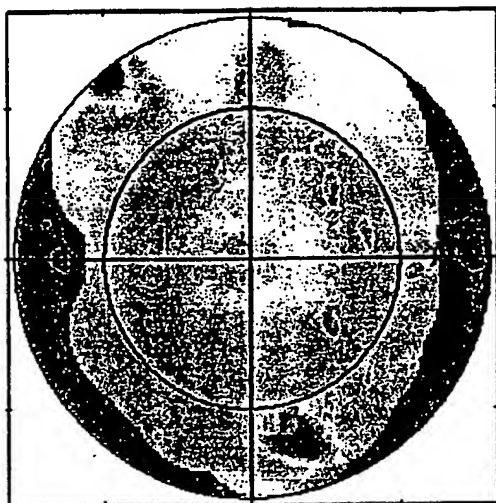


Figure 6

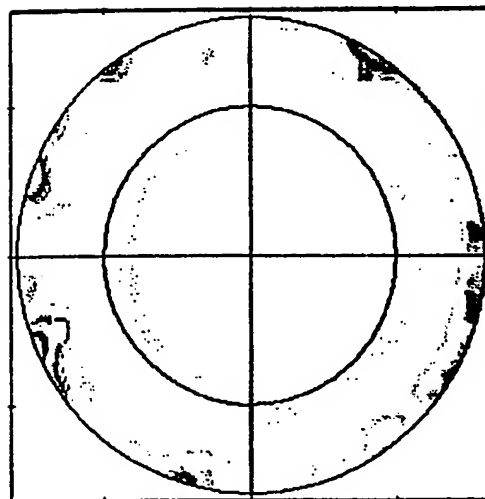
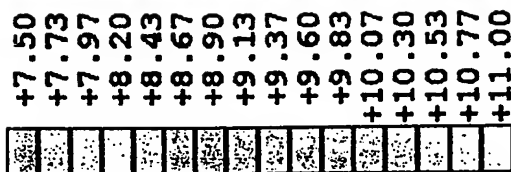
Theoretical Lens Power Distribution  
Figure 7



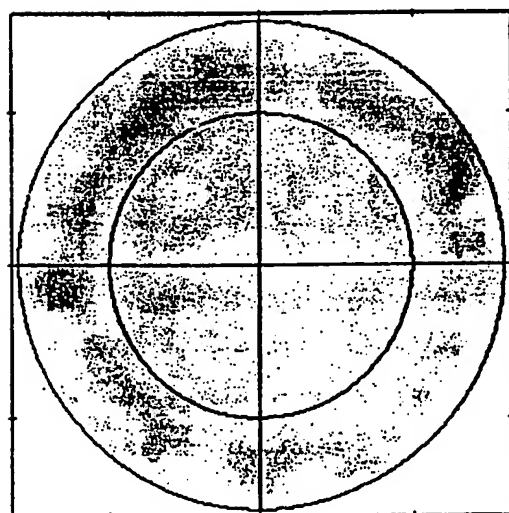
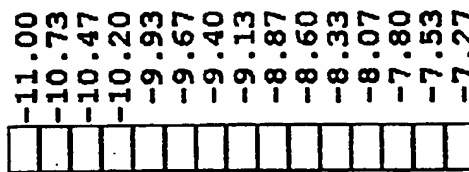
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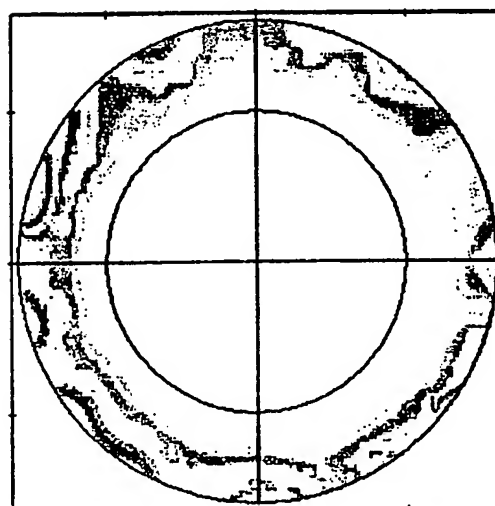
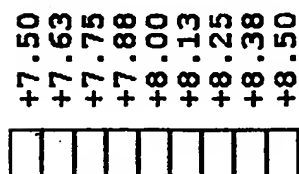
Power Map of lens 2, pair A - FIG 8B



Power Map of lens 2, pair B - FIG 8D



Power Map of lens 1, pair A - FIG 8A



Power Map of lens 1, pair B - FIG 8C

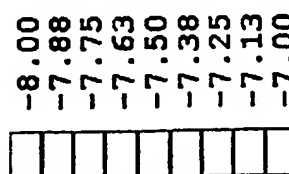


Figure 8

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 00/00445

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G02C7/04

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G02C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 742 466 A (JOHNSON & JOHNSON VISION PROD) 13 November 1996 (1996-11-13) column 6, line 15 - line 43	1
A	EP 0 742 462 A (JOHNSON & JOHNSON VISION PROD) 13 November 1996 (1996-11-13) claim 1	1
A	US 5 050 981 A (ROFFMAN JEFFREY H) 24 September 1991 (1991-09-24) claim 1	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

### \* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search

25 May 2000

Date of mailing of the international search report

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European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
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Sarneel, A



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Information on patent family members

Int. Jonal Application No

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